ABSTRACT

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CROSS SECTIONAL ESTIMATES OF INDUSTRIAL DEMAND FOR WATER

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The purpose of this thesis is to estimate the demand for water by the manufacturing sector of the United States of America. It is concerned with determining the price of water extracted from river basins, reservoirs, creeks, etc. supplied through publicly owned treatment works(POTWS) that justify the use of recirculated water as opposed to the direct use of water from privately owned treatment facilities.

Regression analysis is used to empirically evaluate theoretically expected outcomes in comparison to observed water consumption. Using a sample of water use data from manufacturing industries for selected years, a statistically significant relationship have been found between water cost

and water demand. A major finding is that the cost of treating previously used water to enable it to be reused in the production process relative to the price of water purchased directly from publicly owned treatment works affects demand for water from P.O.T.W.

A second major finding is that industrial water use is quite concentrated. Water using industries (i.e., paper, chemical, petroleum, metal, and transportation), account for the lion's share of water use in manufacturing establishments. Availability of water was found to represent an important factor in industrial location decision for these industries. However, improvements in technology that enable industries to recirculate water have reduced the importance of water availability as a locational factor.

This thesis enhances the general understanding of the influence of water availability on the structure of production and industrial location. It also depicts how changes in the cost of water affect industrial demand for materials, capital and labor.

CROSS-SECTIONAL ESTIMATES OF INDUSTRIAL DEMAND FOR WATER

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CHAPTER I

INTRODUCTION

All sectors of the economy require the use of limited natural resources for production. Water is no exception. The growing demand for water resources requires the same type of concern in manufacturing as the use of any resource. Increasingly, strict treatment requirements under P.L. 92-500 and the Federal Water Pollution Control Act of 1972 and the Safe Drinking Water Act of 1984 have substantially increased the cost of water to industry.[1] Although the cost of water is a concern to all industries, it is of particular importance to steel, chemical, paper, petroleum, and transportation industry.[2] These industries comprise the "lion's share," of industrial use of water in the United States. (see Table I).

American manufacturing industries consumed 44,494 billion gallons of water in 1978. Gross water (GW) is the total volume of water that would have been required if no

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[1]American Water Works Association, Water Utility Operation Data, (Denver: American Water Works Association, 1984).

[2]Elizabeth E. Lake, W.M. Honneman and R. Sheron Oster, Who Pays for Clean Water: The Distribution of Water Pollution Control Cost. (bolder: West View Press, 1970).p. 190

Table 1

INTAKE AND GROSS WATER PER UNIT OF

OUTPUT, (1973, 1978, 1983)

GALLONS/MILLION DOLLARS

Industry	Year	GW	IW	RC	Cost	Labor	Wages	$/GW[1]	$/IW[2]	$/RC[3]	W/L[4]
Paper & Allied Product	1973	8127	2413	5712	1181.0	309	4693.4	0.145318	0.489026	0.206757	9.244754
	1978	10401	1963	8438	357.8	491.8	6939.6	0.034400	0.182272	0.042403	14.11061
	1983	1436	1899	5537	308.9	460.8	9736.8	0.068437	0.267983	0.091908	21.13020
Chem. & Allied Products	1973	11099	4176	6923	247.6	535.1	3149.3	0.022308	0.039291	0.035764	9.623061
	1978	12494	4326	8168	799.6	547.8	8136.3	0.063998	0.184835	0.097894	14.88919
	1983	9630	3401	6229	1106.0	496.0	10867.6	0.114849	0.323198	0.177536	21.91048
Petroleum & Coal Products	1973	8138	1283	6875	123.4	95.8	1011.4	0.013371	0.097739	0.01824	10.53741
	1978	8187	1173	7014	308.1	103.1	1983.0	0.037632	0.262639	0.043926	19.23375
	1983	6177	818	5359	352.3	95.1	2723.3	0.089412	0.675183	0.103060	28.63617
Prim. Metal Products	1973	8842	4941	3901	184.3	993.3	10873.1	0.016772	0.030014	0.038013	10.92225
	1978	6479	3392	3087	333.1	920.9	16179.3	0.031412	0.098201	0.107904	17.36922
	1983	5885	2663	3222	434.6	383.1	136442.4	0.077247	0.170709	0.141092	23.31635
Transportation Equipments	1973	1967	242	1735	31.1	1340.6	14833.8	0.025978	0.211157	0.029623	11.06304
	1978	2435	235	2200	110.2	1364.3	23260.8	0.045256	0.468936	0.050090	17.04712
	1983	1011	153	831	224.2	1072.1	26917.4	0.221760	1.465359	0.261303	25.10717

[1]Price of Gross Water(per 1000 Gallons)
[2]Price of Intake Water(peer 1000 Gallons)
[3]Price of Recirculated Water(per 1000 Gallons)
[4]Wage (per 1000 Gallons)

GW - Gross Water Million Gallons; IW - Intake Water in Million Gallons; RC - Recirculated Water in Million Gallons; Cost - Cost of Gallons

Source: U.S. Department of Commerce, <u>Pollution of Abatement Costs and Expenditures</u> (1973-1983); Bureau of Census.

TABLE 2

Cost of Gross Water 1973, 1978, 1983 and 1986
Compared to the Five Major Industrial Groups
(Manufacturing Water Use)
Millions of Dollars

Industries	1973	1978	1983	1986
Paper	$118.1	$357.9	$508.9	$585.7
Chemical	$247.6	$799.6	$1,106.0	$1,301.8
Petroleum	$193.5	$308.1	$552.3	$578.0
Metal	$148.0	$333.1	$454.3	$509.4
Transportation	$51.1	$110.1	$224.2	$338.5
Sub-Total (Five Major Industries) &	$758.3	$1,908.9	$2,845.7	$2,499.9
Percentages	76.45%	64.85%	72.18%	51.86%
All Industries	$993.3	$2,550	$3,943.2	$4,820.2
& Percentages	100%	100%	100%	100%

Source: U.S. Department of Commerce, Pollution Abatement Costs & Expenditures (1973, 1978 and 1983); Bureau of Census, Current Industrial Reports, (MA 100/74-1).

water had been recirculated or reused. Gross water consists of intake water(IW) and recirculated water(RW). The amount of intake water used was only 19,992 billion gallons in 1978. Thus, less than one-third of water used by American manufacturing industries in 1978 came from the intake or directly piped water (city water).

Table I shows the trends in consumption of gross water, intake water, and recycled water (1973, 1978, & 1983). It also shows the price of water per thousand gallons for the past ten years. It can be observed that as the price of water increases, the consumption of water decreases. It means that the price of water has an important part in determining the consumption of water.

With the high cost of industrial water, research on the subject of changes in price of water are needed. The rising cost of water possibly indicated that a significant portion of water recirculated has serious quality water problems,[3] and it is important to enhance the understanding of the nature and extent of these problems.

Although water use has fallen, the cost(dollar/thousand gallons) has increased substantially. As Table 2 indicated, the total cost of water used by manufacturing industries in the United States increased from $993.3 million in 1973, to $3,943.2 million in 1983. Some of the increase in water cost

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[3].J. Kindler and C. S. Russell. Modeling Water Demands, Academic, Inc. Orlando, FL: Harcourt Bruce Jovanonich, 1984. p. 195

is a consequence of industry responding to more stringent treatment requirements.[4]

Between 1973 and 1978, there was an 11 percent increase in water use by the chemical industry. The transportation industry experience a 19 percent increase in gross water. However, there was a decline in gross water after 1978 for both the chemical and transportation industries. All industries showed a decline in intake water use from 1973 to 1983, except the chemical industry, whose demand was essentially unchanged. (see Table 3).

The intake/gross water ratio continues to decline between 1964-1983 period. There was a minor downward trend in the intake water/output ratio. The paper industry indicated a low intake/gross water ratio, but shows high use rates. (see Table 4). This might be due to the recirculation of intake water and sensitivity of management to water-using industries that have stressed recirculation of intake water to obtain their production requirements, and at the same time minimize the cost of water input.

When the cost of intake water rises, and it becomes economically feasible to recirculate, the plant will minimize the cost of water by recirculating. But when the price of intake water rises to equal or exceed the cost of

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[4]J. Royce Ginn and Robert A. Leone, The Metal Finishing Industry. (Vienna: International Atomic Energy Agency, 1968).p.9

TABLE 3

Percent Change in Gross and Intake Water
Between 1973 and 1978, and 1978 and 1983
In Million Gallons

Industries	1973	-1978	1978 -	1983
	GW	IW	GW	IW
Paper	-0.24	0.22	-0.03	-0.40
Chemical	0.03	0.11	-0.27	-0.29
Petroleum	-0.09	-0.004	-0.30	-0.33
Metal	-0.45	-0.36	-0.27	-0.10
Transportation	-0.03	0.19	-0.54	1.401
All Industries	-0.16	0.024	-0.29	-0.32
Other Industries	-0.16	-0.033	-0.35	-0.22

Source data: U.S. Department of Commerce, Census of Manufacturers; Percent change in intake and gross water(1973, 1978, & 1983).

TABLE 4

WATER USE IN U.S. MANUFACTURERS FOR ESTABLISHMENTS

WITHDRAWING 20 MILLION GALLONS OF WATER OR MOR ANNUALLY

SIC	INDUSTRY	IW/Q 1964	IW/Q 1973	IW/Q 1983	IW/GW 1964	IW/GW 1973	IW/GW 1983	GW/Q 1964	GW/Q 1973	GW/Q 1983
20	FOOD & KINDRED PROD.	0.91	0.81	0.53	1.37	1.09	0.99	0.66	0.76	0.53
21	TOBACCO PRODS.	0.81	1.27	1.33	0.17	0.18	0.54	4.73	6.91	2.47
22	TEXILLE	0.54	0.40	0.28	0.63	0.48	0.46	0.86	0.83	0.60
24	LUMBER & WOOD PRODS.	0.87	0.59	0.32	0.83	1.17	0.46	1.04	0.51	0.67
25	FURNITURE & FIXTURES.	0.33	0.42	0.20	0.86	0.76	1.14	0.89	0.55	0.17
26	PAPER & ALLIED PRODS.	0.77	0.60	0.40	0.89	0.71	0.61	0.86	0.84	0.66
28	CHEMICAL & ALLIED PRO.	1.48	1.46	0.46	0.81	0.60	0.56	1.84	2.42	0.83
29	PETROLEUM & COAL PRO.	0.75	0.48	0.33	0.76	0.52	0.44	0.99	0.91	0.76
31	LEATHER & LEATHER PRO.	0.58	0.34	0.33	1.10	0.88	0.94	0.53	0.40	0.35
32	STONE. CLAY & GLASS PRO.	0.57	0.37	0.31	1.24	0.89	0.89	0.46	0.41	0.35
33	PRIMARY METAL INDUST. FABRICATED METAL	0.91	0.72	0.59	0.88	0.72	0.52	1.03	1.00	1.15
35	MACHINERY EXCEPT ELECT.	1.00	0.61	0.35	0.77	0.52	0.52	1.29	1.17	0.67
36	ELECTRICAL & ELECTRONIC EQUIP.	0.53	0.30	0.11	0.43	0.30	0.25	1.25	1.00	0.44
37	TRANSPORTATION EQUIP.	0.89	0.53	0.36	0.41	0.13	0.15	2.17	4.23	2.31
38	INSTRUMENT & RELATED PRODS.	1.08	0.68	0.36	1.08	0.68	0.30	0.99	0.88	0.47
39	MISCELLANEOUS	0.41	0.25	0.09	1.68	0.53	0.30	0.61	0.88	0.47

IW/Q: INTAKE WATER PER UNIT OF GROSS OUTPUT. IW/GW: INTAKE WATER AS PERCENT OF TOTAL INTAKE WATER FOR ESTABLISHMENTS WITHDRAWING 20 MILLION GALLONS OF WATER OR MORE ANNUALLY. DATA ON INTAKE WATER (IW). GROSS WATER(GW) ARE TAKEN FROM BUREAU OF THE THE LABOR STATISTICS 1964, 1973, AND 1983. GROSS OUTPUT(Q) WAS TAKEN FROM THE CENSUS OF MANUFACTURERS.

recirculating water, substituting recirculated water as well as other inputs (capital or labor, etc.) for intake water

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take effect.

There is an inverse relationship between the cost of water and the demand of water. As the price of water rises, other factors remain constant, industrial demand for water declines. The quantity of intake water demanded depends negatively on the price of intake water and technical progress in connection with the reuse of water. It depends positively on the price of complimentary inputs and on gross water(GW) requirements.

For example, consumption of intake water and gross water declined by 49.3 percent and 28.3 percent respectively between 1978 and 1983. This decrease was caused by the sharp increase in the cost of water, new treatment requirements, adoption of improved technology, and locational factors.

Water needs some kind of technical improvement prior to its use in the production process. The process is increasingly expensive and can have a significant impact on the industrial production. It raises the price for water consumption and demand for complementary inputs such as labor, capital and materials.

Among manufacturing industries, paper, chemical

Table 5

Summary of Total Water Consumption and Percent of Gross and Intake Water Used in 1973, 1978 and 1983 in Billion Gallons.

Industry	1973		1978		1983	
	GW	IW	GW	IW	GW	IW
Paper & Allied Products	8,127 19%	2,415 16%	10,401 23%	1,963 15%	7,436 22%	1,899 19%
Chemical & Allied Products	1,109 26%	4,175 28%	12,949 28%	4,326 33%	9,630 18%	3,401 34%
Petroleum & Coal Products	8,158 19%	1,283 9%	8,187 18%	1,173 9%	6,177 18%	819 8%
Primary Metal Products	884 20%	4,941 33%	6,479 15%	3,392 26%	5,885 17%	2363 24%
Transportation Equipments	1,967 5%	242 2%	2,435 5%	235 2%	1,011 3%	153 2%
Sub-Total Five Major Industries	38,193 89%	1,305 88%	39,996 89%	11,089 85%	30,139 88%	6,634 87%
Other Industries	5,220 11%	1967 12%	4,498 11%	1,903 15%	3,696 12%	1,405 13%
Total Industry	43,413 100%	15,024 100%	44,494 100%	12,992 100%	33,835 100%	10,039 100%

Source: Bureau of Labor Statistics, Census of Manufacturers(1973, 1978, 1983),WATER consumed by Manufacturers in billion gallons.

products, primary metal industries, petroleum refineries, and transportation equipment industries are usually the most significant water users. These five sectors accounted for 85 percent of the total intake water used in manufacturing in the United States. (see Table 5).

In the United States, manufacturing is geographically concentrated within a few areas in particular, and within those areas which are adjacent to metropolitan regions. The demand for water corresponds roughly to the location of manufacturing. Manufacturing concentrations and water demand may be expected to continue for the foreseeable future, modified in detail, but not in major characteristics. Geographic concentration of demand intensifies the supply problem as requirements increasingly exceed amounts locally available. This helps to explain why cost of water is rising in some industries.

The concentration of manufacturing industries east of the Mississippi River, and north of the Ohio River and along the Potomac, this area has been called, "the manufacturing belt.[5] These regions represent about 85 percent of all the industries in the United States.

The manufacturing industries are heavily concentrated. However their outputs are widely distributed over the United States, and increasingly in regions outside the major region

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[5]Russell G. Thompson, Forecast Water Demands. (Arlington, VA: U.S. Department of Commerce, 1971). p. 128

FIGURE 1: Summary of water use statistic by percent for the five major intake and gross water users within the manufacture industries in the U.S. 1983.

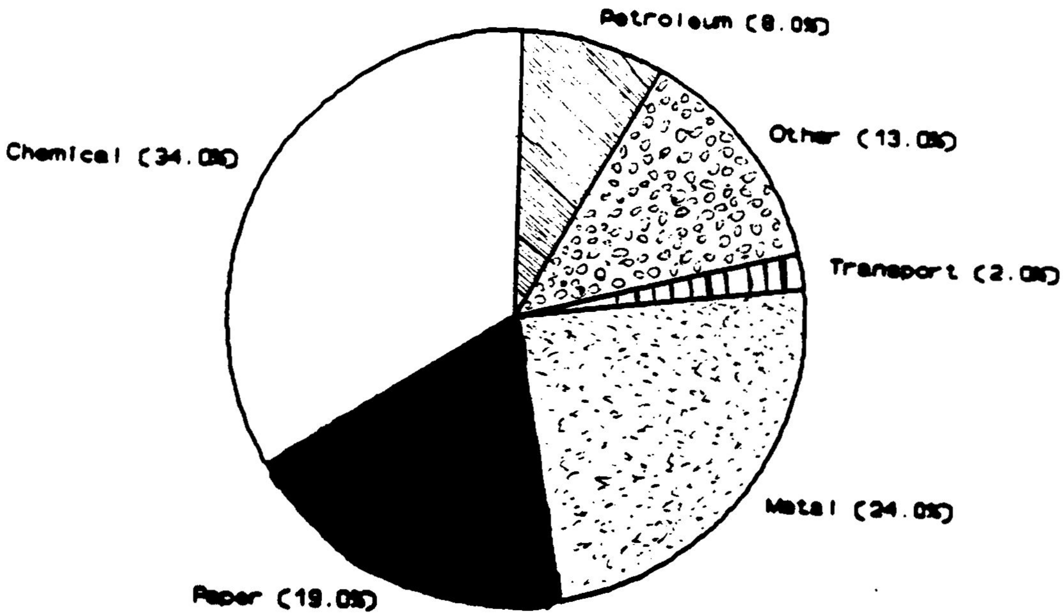


Illustration 1: Gross Water 1983

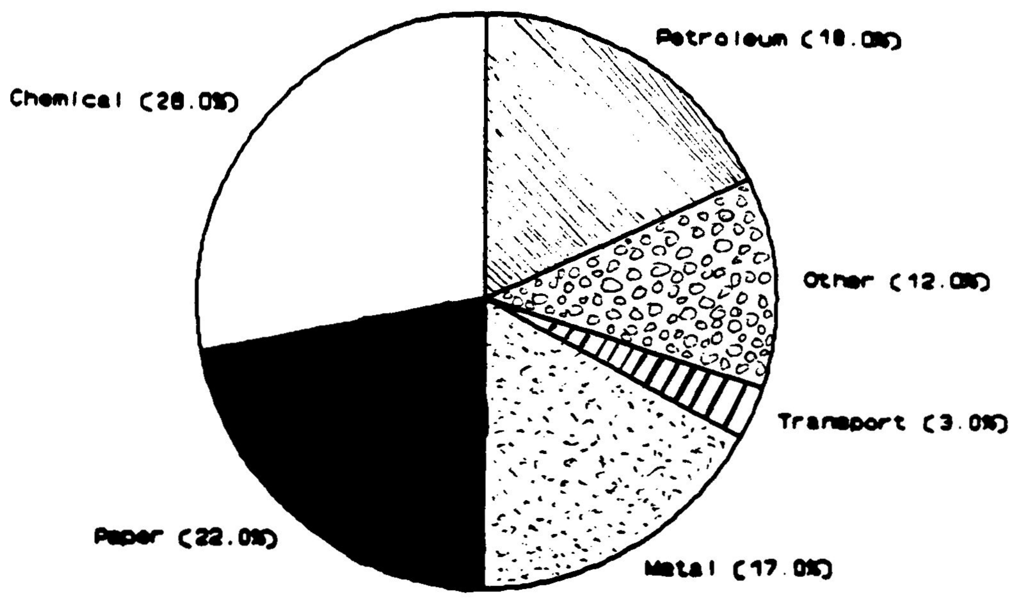


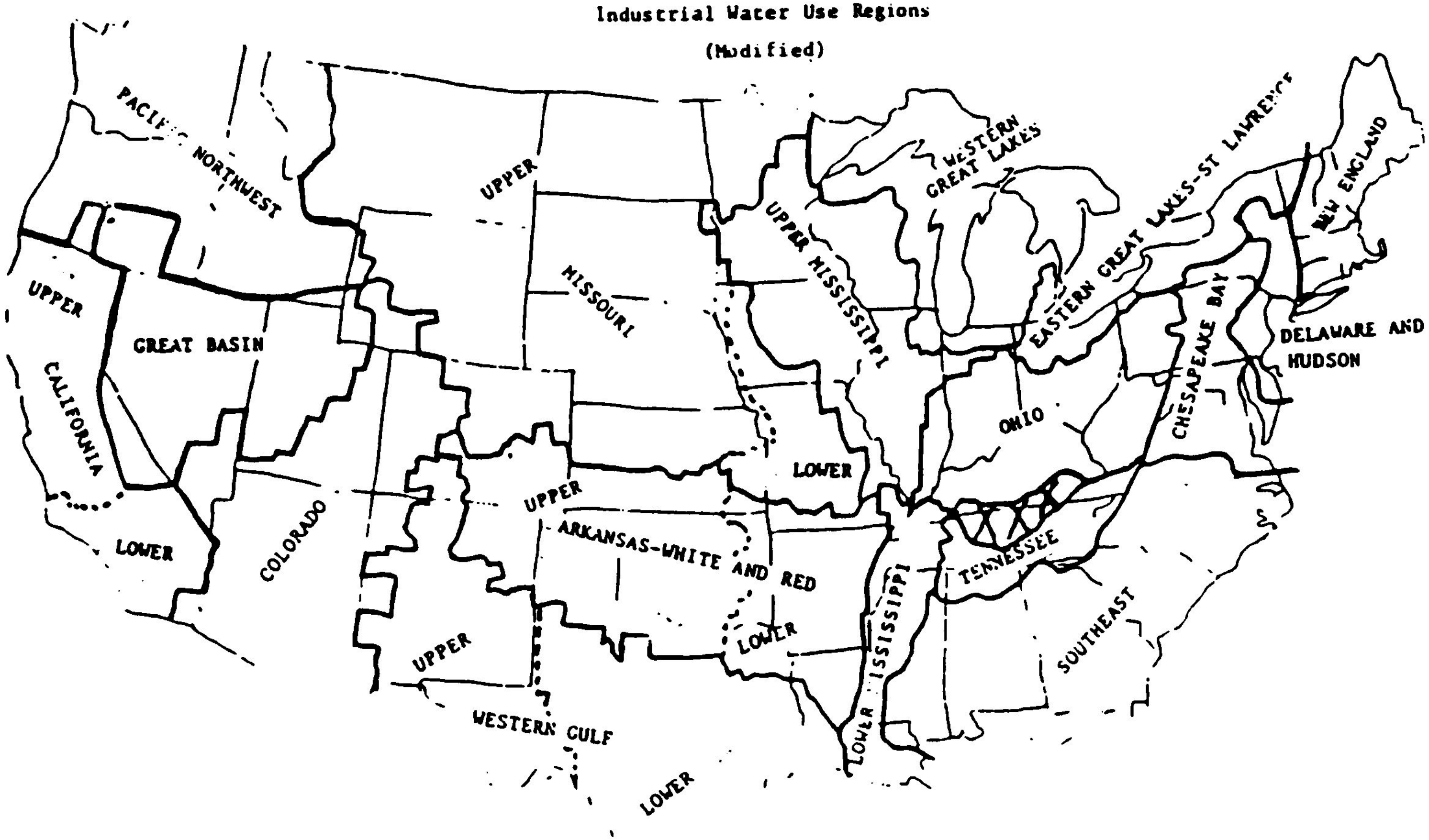
Illustration 2: Intake Water 1983

SOURCE: Bureau of Labor Statistics, Census of Manufacturers, Bureau of the Census 1983.

Figure II.

Industrial Water Use Regions

(Modified)



of concentration. Some of the principle factors (water, technology, labor, transportation, location etc.) that lead to concentration also operate to develop other additional industries. For example, the most populated cities produce a share of the newspaper far greater than their share of the population. Quick transportation facilities, with frequent scheduled departures, can take the papers in a short time after they are printed to customers at considerable distances.

The point that industrial water is even more concentrated than manufacturing as a whole, appears to be due primarily to the heavy demand of a few classes of industry.[6] As indicated in Figure 1, primary metal industries consumed 24 percent, paper consumed 19 percent, chemical consumed 34 percent, petroleum consumed 8 percent, and transportation equipment consumed 2 percent of water used in the manufacturing groups.

About two-thirds of the industrial water intake appears to occur in three states - New York, Pennsylvania, and Ohio, which account for almost 40 percent of industrial water use nationwide. Figure 2, a map of the United States, shows the industrial water use areas.

Metal industries are more concentrated in the manufacturing belt than other manufacturing industries in general. Petroleum refining is almost exclusively

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[6]Charles B. Garrison. "Effect of Water Resources on Economic Growth in the Tennessee Valley Region." Ph.D. Diss, University of Tennessee, 1971. p. 76.

concentrated in three areas--Louisiana, Texas-Oklahoma, and California. Paper industries are concentrated in the coniferous forest areas of northern New England, Lake states, the Gulf South, and Washington.

The cost of industrial water can be divided into four major components; supply, treatment, distribution and testing. These costs are traditionally evaluated separately, even though they are interdependent. The cost of treatment depends on the quality of the supply. The cost of distribution depends on the location of the treatment plant. The distribution system also depends on the stability of the water and, therefore, on the treatment provided. The treatment depends on the outcome of the testing of the water.

The growing awareness of pollution problems and the emphasis on their connections have resulted in many industrial plants spending significantly more for water treatment than for direct water intake.[7] Bower cited case studies of waste disposal costs for a variety of industries including steel, paper, petroleum refinery, and chemical manufacturing.

In the manufacturing sector, water must meet certain

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[7]Blair Bower, The Economics of Industrial Water Utilization in Water Research, eds. Allen V. Kneese and Stephen C. Smith (Baltimore, MD: The John Hopkins Press, 1966), 28.

Table 6

Pollution Abatement Gross Capital

COST Expenditures in million dollars

1973, 1983, 1978, AND 1986

SIC	Industry	1973	1978	1983	1986
26	Paper	160.0	189.2	85.4	97.29
28	Petroleum	96.1	100.7	164.7	203.7
33	Chemical	214.6	392.9	187.4	236.5
37	Transportation	41.7	57.9	224.2	80.4

Source: U.S. Department of Commerce, Pollution Abatement cost and Gross Capital Expenditures(Gross Water Cost in Million Dallors 1973, 1978, 1983 & 1986).

than one type of treatment process, the costs for this plant are increased as the sum of the costs of activities requires to meet specific standards are higher. In most cases, costs are estimated for three abatement levels; 1977 the Best Practicable Treatment Act (BPTA), 1983 the Best Available Technology Act (BATA), and New Source Performance Standards (NSPS).[8]

Table VI presented estimates of pollution abatement costs for five industries that are major water users in the manufacturing sector. It can be observed that the costs of extracting waste materials from water, cost billions of dollars over the years. The cost of water has increased due to high cost of pollution, recycling water and market price.

Water pollution control in recent years has made enormous strides. The solutions are as particular as the problems encountered in each industry. They have reduced water use and raised water cost.

The cost of water has been underestimated. A finding of significant price responsiveness to differential water costs suggests a need for additional research that seeks to determine the impact of water quality on water cost, rather than attempt to identify direct linkages between quality and use.

The chemical industry is most often located near

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[8]J. Kindler, and C. S. Russell. Modeling Water Demands. Academic, Inc. Orland, Fl: Harcourt Bruce Jovanonich, 1984. p. 30

The chemical industry is most often located near industrial markets for the products. Large manufacturing plants that are heavy water using industries, choose locations after carefully weighing many factors. Water supply is one of those factors. The concentration of demand is one of the primary factors in the industrial water problem. It results from the concentration of manufacturing in large industries, in areas offering the most conducive continuation of advantages, and in urban aggregation.

STATEMENT OF THE PROBLEM

Earlier studies have not found water to be a significant input. In this thesis, it is argued that the failure to find a relationship between water and output is due to the failure to distinguish between recirculated water and intake water. More specifically, the paper argues that the rising cost of intake water makes it economically efficient for industries to expend resources to render previously used water reusable. Thus, while industrial demand for intake water might decline as production increases, gross water use (intake water and recirculated water) increases with production. To be able to reuse water, there are additional needs for capital, materials, and labor. Thus, it is the relative cost of intake water, as opposed to the per gallon cost of cleaning previously used water, that drive the demand. In this degree, the state of technology and the cost of capital, labor, and materials are important in determining the demand for intake water.

This makes the demand for intake water more sensitive to price changes. This has not been investigated by others, yet it would explain the general result that water is an insignificant input to production. Therefore, we theorize that existing water resources will be conserved if the price of intake water is allowed to rise by enough to exceed the cost of recirculating water. Those who consider industrial demand for water insensitive to price, ignore an important option for policy makers to conserve the use of a limited natural resource.

HYPOTHESIS

This thesis investigates the influence of several factors on industrial water demand and examines the impact of technological changes on the quantity of water use.

The research hypothesis is that the long-run, price elasticity demand for industrial water demand is greater than previously literatures suggest. It also states that an increase in the relative price of intake water to recirculated water should inspire plants to make more use of recirculated water and less of intake water. Finally, other things being equal, a rise in the cost of gross water is awaited to decrease the consumption of water input.

Historically, water has not been treated as an imperfect factor for the industrial sector. It is reasonable to examine more closely the relationship between the water cost and water demand by manufacturing industries.

THE PURPOSE OF THE PAPER

The purpose of this study was to examine empirical indication about changes in the industrial water use in order to enlarge our understanding of the impact of changes in the cost and quality of the water on technological changes in process design and plant location decisions.

The second purpose of the study was to construct a model which can be used to determine the demand for intake water and gross water in the plants. The third purpose was to identify the factors that influence the intake water function and gross water function. The purpose was also to estimate the relationship between intake water and recirculated water and the effect of the cost of recycled water on the demand of intake water.

THE ORGANIZATION OF THE PAPER

This study organized as follows: Chapter 1 presents the trends in water use by major industries from 1954 to 1983. It also focus on the five major manufacturing industries that consumed 85 to 90 percent of industrial water in the United States. Chapter 2 reviews revellent literatures on industrial water demand. Industrial water demand model is constructed in chapter 3. Intake and gross water demand equations are derived, and important variables that influence the demand for industrial water are identified and analyzed. In chapter 4, regression analysis is used to implement the model posited in chapter 3. Parameters derived from theoretical model are used to estimate demand for intake water and gross water in 1956, 1964, 1968, 1973, 1978 and 1983. Chapter 5 presents conclusions from the research and offer suggestions for future research.

CHAPTER 2

REVIEW OF LITERATURE

In order to develop the theoretical analysis, several studies of the relationship between water resources and the level of economic activity were reviewed. None of the studies took a position on the question of relative impact on force of water investment, as compared to other alternatives as a source of economic growth. Some of the key research designs are not definitive, and others lack theoretical framework that would have led to a functional relationship. However, the findings from these studies are useful in that they provide useful insights into certain developmental implications of water investment.

A study conducted by Ben-David extends a theoretical model of water supply-demand relationships to originate a statistical test of the hypothesis that water accounts for an important part of the total cost structure in some industries. Therefore, water plays an important role in the location decision of those industries. From the eastern half of the United States, the data were collected from counties in 14 states and multiple regression analysis[9] was

9Shaul Ben-David, "Effects of Water Development on Location of Water-oriented Manufacturing." in Estimation of First Round and Selected Subsequent Income Effects of Water Resources, ed. George S. Tolley (Springfield, VA: Clearing House for Scientific and Technical Information, 1970) 89.

used to determine the influence of several factors on water demand.

Water-oriented manufacturing (defined by Ben-David, as those industries in which water had an important part in the production cost structure) employment was regressed on manufacturing wages, market potential non-water-oriented employment, and water availability, measured by low-flow miles in all stream segments of the county. Water availability was found to be a significantly related to employment in the water-oriented industries. He indicated that changes in water availabilities in areas where water was not available in abundance was associated with increases in employment in water-oriented industries. Based upon partial regression coefficients on the logarithm of water availability of an area in which water is not abundant, water did in fact make the area more attractive to water-oriented industry. More specifically, the results indicated that an increase of 0.169 percent in employment for a one percent decline in water availability.

The growth implications of multiple purpose water projects in 61 countries during the 1948-1958 period was examined by Cox, Groven, and Siskin and in latter study.[10]

10Thomas Cox, C., Wilford Grover and Bernard Siskin, "Effect of Water Resource Investment on Economic Growth," Journal of the Science of Water 7 (May 1971): 37-39.

Due to the narrow geographic scope of their observations, they found no statistically important relationship between project size and regional growth. The study concluded that variables measuring the availability of water and water-related services were not chosen out of ample set of explanatory variable for inclusion in any of final regression equation specified by a step-wise technique.

There were some important methodological problems. For example, the relative contribution of any one variable to the ratio of explained mean square to unexplained or error mean square was conditional on the variables already in the equation. It is quite probable, given the number of variables considered, that the variables included in equation were functionally dependent on other water variables. The explanatory power of the latter had already been largely accounted for by the former. In such a case, the addition of the water variable could hardly be expected to result in an important increase in the equational statistics (F), and thus, they would not be selected for final inclusion. Since the data were drawn simply on rural counties in one area, the results could merely be narrowly applied.

The study by Howe deals with the relationship between water availability and economic growth in the United States, over the 1950-1960 decade.[11] The study used analysis of

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11Charles W. Howe, "Water Resources and Regional Economics Growth in the United States, 1967 - 1968. "The Southern Economic Journal 4 (April, 1967): 34.

variance techniques to decide if there were important differences in the rate of economic growth among regions (for example, counties), ranked or classified with respect to water availability. The conclusions were not positive. Areas without large water resources, as measured by stream-flow, availability of water transportation, and average annual runoff, were not distinguished by below average growth, while regions well gifted with water, were not assured fast rapid growth. The conclusion was a bit strong, due to the fact that there were certain problems in Howe's research design.

The study pointed out that water availability and water transport do not outweigh other attributes possessed by areas which make them attractive or unattractive as a lure to different industries. It indicates that water resource developments are likely to be poor tools for accelerating regional economic growth if market access, factor availabilities, and quality of life factors are not present.

The conclusion was not directly from the analysis. Howe indicates that, "...water resource developments are likely to be poor tools for accelerating regional economic growth... ." Howe did not carefully examine the relationship between water availability and growth, nor investment and growth. It was apparent that water availability did extend growth in many of these counties, but that the development consequences had been largely exhausted by 1950. Chicago, Illinois, is a case in point. Many advantages during the early development of cities (Lake Michigan and the Chicago River) most likely helps to explain the important part of the city's economic development. By 1950, many of their advantages had been captured, and the city's population experienced a decline between 1950-1960.

Water use and availability also have been examined for selected small communities in Mississippi. The objective of the study was to enable these counties to effectively utilize the resources at their disposal when they attempt to secure additional industries. It was also to assist them with their industrial water supply problems.

To determine the extent that industrial water has aided in attracting industry into or near the communities selected for this study, questionnaires were mailed to 350 industries taken from the directory of Mississippi manufacturers. Sixty-five of the respondents answered "yes" when asked if they were planning to expand within five years. Forty-one respondents answered "no," 14 did not know, and three did not answer. None of the 41 respondents who answered "no" gave water problems as their reason for not expanding at their present location. It was observed that "hometown or owner" and "cost" or "availability of labor", were by far the most important factors in the decision to locate in respective communities.

Water was listed as one of the location factors. However, it did not play a primary role as a factor in the

initial location decision for the majority of the respondents. Only 16 of the respondents
indicated water as a primary factor in their initial location decision. Fifteen of the 16 firms ranked water as the number one factor in their location decision.[12]

When asked whether or not water was an important factor in their decision to locate in the area in which they are located, 25 of the respondents indicated that it was important. This answer is contradictory, to a certain degree. Since only a total of 16 firms ranked water among the most important factors affecting their location decision, it appears that water is secondary, rather than a primary location factor, to some of these firms.

Twenty-two industries reported that they used more than one million gallons of water per month. The water demands of many industries range from several hundred gallons of water per month, to one million gallons per month. This points to the fact that although water is not a primary factor in the location decision of many firms, large quantities of water may be necessary for their operations.

Although only 25 respondents indicated that water was an important factor in their decision to locate in the study, 57 of the respondents indicated that the quality (chemical

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12Guy T. Peden, Jr., Van Oliphant, The Availability of Water for Industrial Uses in Selected Small Communities n Mississippi, (Oxford, MS: Bureau of Business and Economic Research State College, 1967).

content) of the water was important for this operation. It was indicated that 78 percent of the industries get their water supply from city wells.

It was concluded that water was not a major problem in the region because only 25 firms indicated water was an important factor in their decisions to locate at their respective sites. It was found, however, that many firms in the study area use large quantities of water in their operations and that the chemical quality of the water use is important to them. None of the industries responding to the questionnaire have experienced any major water problems.

Robert A. Lecher and others studied the major changes in industrial water use technology and factors contributing to these changes. The study objective was to present findings of a study designed to contribute to the understanding of some of these in the cost and quality of water on technological changes in process design and plant location decisions. The study indicated that water is a necessary, but not sufficient condition for continued growth in water-using industries. Geographic patterns of industry location appear to be shifting toward areas more favorably endowed with water resources. Regional and temporal variations in the recirculation of water are also documented.

The findings suggest that water for industrial processing is not likely to be a major location determinant; rather, water for transportation may be a more important location determinant.

The paper concluded that industrial demand for water is far from inelastic in the range of price changes now being experienced. They appear to be clear trade-offs between water-use and more capital extensive process design. Using cross-section sample data on water use in individual manufacturing plants, the authors found a statistically significant relationship between water cost and water demand, with demand elasticities on the other of 0.5 to 1.0. The authors also suggested that their study falls short.[13] I n summary, the empirical research on the subject is somewhat confusing. The determination of water benefits is less than satisfactory from a conceptual or theoretical point of view. However, there are some positive benefits from water that cannot be denied. For example, there are various economic benefit estimates of water quality enhancement, although most of them focus on limited objectives, such as the value of a single water resource in a small region.

From our literature review, we observed that there is some positive relationship between water and employment growth, specifically that which is water-intensive. The degree of the relationship at the individual industry level is

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13Robert A. Leon, J. Royce Ginn, and Art-Loh Lin, Changing Water Use in Selected Manufacturing Industries (Springfield, VA: National Technical Information Service, 1974), 122.

definitely still uncertain. In some industries, water was found to be productive input of secondary importance, and one for which there existed several sources of supplied (e.g., recycling, self-supplied through wells, purchase of municipal water, etc.). Due to the unique characteristics of the resource, suggest that it might be difficult to use statistical tools to estimate the effects of increased supplies and or quantity.

While there is a considerable discrepancy between the importance of water, and less significant from a theoretical point of view. The current study concerned with Ben-David's viewpoint on the role of water in an industry. That is, water plays an important part of the total cost structure in some industries. Other studies need more investigation before making a sound decision on each result.

CHAPTER 3

THEORETICAL RESULTS

This chapter outlines a theoretical framework and to analyze the effects of causal factors hypothesized to affect changes in the intake water and gross water. Intake water is treated as an input to the production of final output. Gross water demand is derived from the production of final output under the cost minimization principle of factor combinations subject to prevailing technological conditions.

GROSS-WATER DEMAND EQUATION

Consider a production function in which an industry utilizes four variable inputs to produce final output. Let us consider a Cobb-Douglas production function:

$$[1] \qquad Q = A.e^{mt}.GW^{a}{}_{1}.Mq^{a}{}_{2}.Lq^{a}{}_{3}.Kq^{a}{}_{4}$$

where final output Q, is a function of gross water, GW, Materials M, Labor, L, and Capital K. In equation [1], A is a positive constant that operates as a converter, m represents the proportional rate of technical progress, while t is time. The sum of the separate elasticities of production a_1 , a_2 , a_3, and a_4 measures the returns to scale. It means that when the sum of a_1 , a_2 , a_3 , and a_4 equals unity, the production is homogeneous of degree one. If the sum of elasticity coefficients is greater than (smaller than) unity, return to scale are increasing (decreasing).

There is an assumption that inputs in this production function are substitutable. Thus water is a complement to other inputs (e.g., materials, labor, etc.) in production function.

The primary goal of an industry is to minimize the cost of producing predetermined output using water and other inputs. To even up the cost and benefits in using a special input in a certain quantity, the industry is concerned not with the cost of using that particular input, but the overall cost of production which will be affected by the use of the input. For example, when there is an increase in the price of water, it may not really mean that the water per unit of output will drop because of the cost of water. The price of water might be less important in the total cost of production. It may be the relative price of water and non-water inputs that are more important to the plant. It may also be the problem of less quality intake water which requires expensive pretreatment that has driven the price of water up.

The sum of quantities of inputs (gross water, materials, labor, and capital) multiplied by their respective prices equals the cost of total production. It is assumed that aggregate cost of production is:

[2] $C_H = pGW + gM_q + wL_q + rK_q$

In the equation (2) C_H is the total cost of production, and p is the price of gross water ($/1000 gallons). In our analysis, it must be noted that gross water consists of intake water and recycled water, gross water. Therefore, until intake water equation is derived, p is the price of recycled water or reused water. The g is the unit price of materials, w is the wage rate of the variable input labor, and r is gross rate of return to capital. Again p is the price of gross water, and it is equal to the average cost of materials, labor, and capital incurred in the withdrawing intake water, recirculating water, and discharging effluent water.

It is assumed that the plant desires to minimize the cost of producing a particular final output. In this case, equation (2) is minimized subject to equation one.

The separate input demand can be derived by totally differentiating the following function with respect to inputs GW, M_q, L_q, K_q, and the lagrangin(λ).

$$[3]\ Z = pGW+gMq+wLq+rKq+ \quad (Q-A.e^{mt}\ GW^{a}{}_{1}.Mq^{a}{}_{2}.Lq^{a}{}_{3}.Kq^{a}{}_{4})$$

The process of deriving the equation below is listed in the appendix I.

$$[4]\ M_Q = \frac{Pa_2}{ga_1}.Gw$$ ratio price of gross water and price of materials

price of materials

[5] $L_Q = \frac{Pa_3}{wa_1} .GW$ ratio price of gross water and wage rate of labor

(6) $K_Q = \frac{Pa_4}{ra_1} .GW$ ratio price of gross water and return to capital.

The least cost condition was used to produce equivalently:

[7]
$$\frac{p}{\frac{a_1 Q}{GW}} = \frac{g}{\frac{a_2 Q}{M_Q}} = \frac{w}{\frac{a_3 Q}{L_Q}} = \frac{r}{\frac{a_4 Q}{K_Q}}$$

When output prices rise, the industry will increase the consumption of water.

In equilibrium, the input price marginal product ratios must be the same for all inputs. For example, input-price-marginal-product ratio of gross water must be equal to materials ratio. The Lagrangian represents the marginal cost of production in the optimum state. The Lagrangian measures the comparative static effect of the constraint constant on the optimal value of the objective function.

We substitute their value of M_Q , L_Q , and K_Q, into the production function and the gross water equation is:

[8]
$$GW = \left\{ \frac{Q}{Ae^{mt}} \left(\frac{ga_1}{pa_2}\right)^{a_2} \left(\frac{wa_1}{pa_3}\right)^{a_3} \left(\frac{ra_1}{pa_4}\right)^{a_4} \right\}^{\frac{1}{a_1+a_2+a_3+a_4}}$$

From equation (8), the quantity of gross water demanded is an inverse function of its own price p and technical progress A. In other words, as the price of gross water rises, the quantity of gross water demanded will decline. This also applies when technology improves, the plant tend to use less gross water.

When the price of the other inputs rise, the industry will use more gross water indicating that water is a substitute for other inputs. But when the price of water gross (p) increases, the plant will reduce on consumption of water and substitute other inputs such as materials, labor, capital, etc.. The plant will use more labor to produce equivalent final output until substitution is not possible.

Dividing equation (8) by Q, we obtain:

[9]

$$\frac{GW}{Q} = \left\{ \frac{Q^s}{Ae^{mt}} \left(\frac{ga_1}{pa_2}\right)^{a_2} \left(\frac{wa_1}{pa_3}\right)^{a_3} \left(\frac{ra_1}{pa_4}\right)^{a_4} \right\}^{\frac{1}{a_1+a_2+a_3+a_4}}$$

where $s = 1 - a_1 - a_2 - a_3 - a_4$. When there are constant returns to scale ie., $a\grave{i} : = 1$, gross water demanded per unit output will not be affected by changing the level of output.

If the $a\grave{i} = 1$, then $1 - a\grave{i} = 0$. It means that the change in output leads to no change in the relative use of gross water. As a result, output changes will not be a factor

Many industrial water researchers have taken the assumption of constant returns to scale and have not recognized or taken into consideration the fact that the price of water is much more than just the price of intake water. If one allows to construct factor demand functions that capture both output as well as substitution effects, price of water could play a major factor in the industrial production.

The Demand for Intake Water

The demand for intake water can be derived in a similar method from the demand for gross water. We assumed that the production function for gross water is:

$$[10]\quad GW = Be^{nt}IW^{d}M_R^{d_2}L_R^{d_3}\ K_R^{d_4}$$

In equation (10), d is a positive constant that operates or produces gross water; n represents the proportional rate of technical progress, and t is time. The total of d_1 , d_2 , d_3 , and d_4 measures the returns to scale for the production of gross water.

Let us assume total water cost to be:

$$[11]\quad C_w = q.IW + h.M_R + w.L_R + r.k_R$$

where q is the price of intake water, h is the unit price of materials used to clean previously used water, w is the unit wage rate of labor used to recirculate water, and r is the gross rate of return to capital used for treating recycled water. In the production processes, water withdrawn is not consumed and not lost, will be discharged and the price of intake water must include the price of withdrawing intake water and the price of discharging effluent water.

Minimizing the total cost of water, equation (11) , subject to equation (10), we obtain:

[12]

$$V = \frac{\frac{q}{d_1\ GW}}{IW} = \frac{\frac{h}{d_2\ GW}}{M_R} = \frac{\frac{w}{d_3 GW}}{L_R} = \frac{\frac{r}{d_4 GW}}{K_R}$$

where V is the marginal cost of gross water.

The values of V is substituted in equation (10) and solve for intake water.

We obtained:

[13]

$$IW = \left\{\frac{GW}{Be^{nt}}\left(\frac{d_1\ h}{d_2 q}\right)^{d_2}\left(\frac{d_1\ w}{d_3 q}\right)^{d_3}\left(\frac{d_1\ r}{d_4 q}\right)^{d_4}\right\}^{\frac{1}{d_1+d_2+d_3+d_4}}$$

The quantity demanded for intake water is an inverse function of the price of intake water and technical progress. The quantity of intake water demand is a direct function of the prices of other inputs and on gross water, suggesting the substitutability of these inputs for gross water.

Dividing both sides of equation (13) by GW, we derive the relative proportion of intake water to gross water.

[14]

$$\frac{IW}{GW} = \left\{\frac{GW^{s}}{Be^{nt}}\left(\frac{d_1 \cdot h}{d_2\, q}\right)^{d_2}\left(\frac{d_1\, w}{d_3\, q}\right)^{d_3}\left(\frac{d_1\, r}{d_4\, q}\right)^{d_4}\right\}^{\frac{1}{d_1+d_2+d_3+d_4}}$$

where $s' = 1 - (d_1 + d_2 + d_3 + d_4)$. It is clear intake increase in proportion to gross water will affect intake water depending upon whether the gross water function is in all inputs unless there is homogeneous of degree one.

Making use of the total cost equation (11) and equation (7), the price or average cost of gross water will be given by:

[15] $$p = \frac{C_w}{GW} = V(d_1 + d_2 + d_3 + d_4)$$

In this equation, gross water marginal cost is V and the marginal physical product of intake water will be MPP. From equation (12) MPP = d_1GW/IW in equilibrium. Then equation (15) can be written as

[16] $$p = \frac{q}{MPP}(d_1 + d_2 + d_3 + d_4)$$

Therefore, the price of gross water will be equal to the price of intake water at equilibrium if $[(d_1 + d_2 + d_3 + d_4)/Mpp] = 1$.

For example when there are constant returns to scale and MPP=1.

The Summaries can be written as:

[17] $\frac{IW}{Q} = \frac{GW}{Q} \cdot \frac{IW}{GW}$

[18] $\frac{GW}{Q} = G\left(Q, \frac{g}{p}, \frac{w}{p}, \frac{r}{p}\ \frac{1}{T}\right)$

[19] $\frac{IW}{GW} = I\left(GW, \frac{h}{q}, \frac{w}{q}, \frac{r}{q}, \frac{1}{T}\right)$

$t(=e^{nt})$ accounts for technical change and has a a reducing effect. The relative prices have positive effects. The effect of final output or gross water will be negative (positive) if the returns to scale is increasing (decreasing) and will be zero if there are constant returns to scale.

In order to complete the model, we assume that the output of the final output Q, is determined under the condition of profit maximization, ie., the price of output being equal to its marginal cost. From this relation and conditions (1), (2) and (3), we obtain:

GW = F(Q, p, g, w, r, T)

IW/GW = F(GW,q, h, w, r, T)

From the above model Q, GW, and IW are endogenous variables while h, p, g, w, r, q, are exogenous variables. Since the price of intake water is the average cost of materials, labor, and capital incurred in obtaining and discharging water , it may depend on the amount of intake water with draw unless the average cost remains unchanged over a relevant range of production. Similarly, gross water may depend on the amount of gross water used. To certain extent, p and q are exogenous variables because of this independence can be estimated by the ordinary least-squares method

From equation (9), the demand for gross water derived from general production function relates the quantity of gross water to price of gross water(p), price of materials relating to price of water, g/p, and the return to capital relative to the price of gross water, price of labor relative to price of gross water, w/p , output(Q), and technology(T). Let us consider the production function of gross water:

$$GW = F(Q, p, g, w, r, T)$$

The second equation which is the demand for intake water-gross water ratio was derived from the general production function (using equation 14) relates the quantity of intake-gross water ratio to a relative price of intake water, price of recycled water, quantity of gross water(gw),wages of labor(w), gross rate of capital return(r) and technology(T).

One of the primary reasons why most water researchers have not identified a relationship between water use and water cost is due to the fact that most water related research in the past and current takes a macroeconomic view of water demand. Perhaps that is the reason why researchers have seen little correlation between aggregate demand for industrial water and water costs. This research is not suggesting that the industries are insensitive to price changes. But it suggests that aggregation hides the marginal adjustments that the paper seeks to identify.[14]

14Henry C. Bamer and Donald J. Motz, Cost Handbook for Industrial Water Users, A Report Submitted to the Office of Water Resources Research, United States Department of the Interior (Pittsburgh, Pa., Cyrus Wm. Rice Division of NUS Corporation, 1969), p. 2.

CHAPTER 4

EMPIRICAL RESULTS

To empirically investigate the hypothesis set fourth in the theoretical model, cross sectional demand for water in 16 manufacturing sectors were estimated for 1973, 1978, and 1983. The intake-gross water ratio is hypothesized to be influenced by unit manufacturing price of intake water (q), unit manufacturing cost of recycled water (p_r), and gross water (GW), as a reflection of output effects. Gross water is hypothesized and influenced by output (Q), price of labor relative to the price of gross water, and unit manufacturing cost of gross water (p). Two equations are estimated ; one for intake - gross water ratio relationship and another for gross water ratio.

(1) $IW/GW = F(GW, q, p_r, h, w, r, T)$

(2) $GW = F(Q, p_g, p, g, w, r, T)$

Note that the price of recycle water was formulated by subtracting intake water price from gross water price to obtain recycle water. $p - q = p_r$. or $q + p_r = p_g$.

IW/GW = intake-water/gross-water ratio

GW = quantity of gross water

IW = quantity of intake water

q = price of intake water

p_r = price of recycled water

h = price of material

w = unit wage rate of labor

r = gross rate of capital return

T = technology/time

Q = output(value added)

p_g = cost of gross water

p = price of gross water

g = price of material

w = unit wage rate of labor

I = total cost of water as a percent of total wage

DATA SOURCES

GW = Gross water is the total volume of water that would have been required if no water had been recirculated or reused. Gross water equals intake water plus recirculated water.

IW = Intake water is the volume of water that goes into the production process. All intake water is not discharged due to consumptive use, and therefore, discharged water can be recirculated. The cost of intake water is the sum of the cost of intake water per gallon plus a proportion of the cost of effluent water per gallon.

p_r = Recirculated water is water that has been reused or treated and recycled. It is part of the gross water.

q = This is the price of intake water per thousand gallons. It is derived by dividing the total cost of intake water by the total quantity gallons of intake-water.

p = The price of gross water per thousand gallons. The price of gross-water was obtained by dividing the total cost of gross-water by the amount of gallons of gross water used.

I = The variable I equal to p_g/w_g, where p_g is the manufacturing cost of gross water; and w_g is the total wages. It is the price of water as a percent of wage.

IW/GW = The intake water-gross water ratio and it measures the intensity of water recirculation.

Q = Gross output figures by manufacturing plant are not readily available. Value-added(VA) for 1973, 1978, and 1983 were used as surrogate. Since value added changes because of inflation in prices current dollar, value added were adjusted respectively by the rates of change in the producers price index for products originating in the industry. The source of data on intake water(IW), gross water(GW), and value added (VA) are the Bureau of the Census, Census of Manufacturing Water Use in manufacturing for 1968, 1973, 1978, and 1983.

r = is the gross rate of capital

w = is the wage rate of labor; and T is the technology used in treatment of water that has been recirculated. It can also be used at time.

The source of information were taken from books, magazine, journals, new papers, literatures and government publications.

REGRESSION RESULTS

TABLE 7-A

DETERMINANTS FOR GROSS WATER-OUTPUT RATIO(GW/Q)

AND INTAKE-GROSS WATER RATIO(iw/gw): FOR MANUFACTURING

Explanatory variables	1973	1978	1983
Constant	-4.148	-7.66	2.63
	(-1.39)	(-2.04)	(0.83)
I	33.77	25.83	16.91
	(4.22)	(3.76)	(2.64)
p	-11.88	-2.01	-3.70
	(-3.86)	(-1.52)	(-4.51)
Q	1.13	1.41	0.45
	(3.84)	(3.76)	(1.43)
R^2	90.1%	79.7%	79.9%
R-sq(adj)	87.6%	74.7%	74.8%
F	36.32	15.72	15.83
N	16	16	16

The T-values are in parentheses.

TABLE 7-B

INTAKE-GROSS WATER RATIO(IW/GW)

Explanatory variables	1973	1978	1983
constant	0.2492	0.497	0.544
	(7.06)	(4.49)	(4.65)
q	- 0.0005	-0.1808	-0.1805
	(0.02)	(-3.66)	(3.81)
p_r	0.0347	0.155	0.162
	(2.34)	(4.32)	(3.75)
p_g	- 0.0131	0.0046	-0.0193
	(-1.00)	(-0.17)	(-0.81)
R^2	78.8%	75.9%	74.2%
R-sq(adj)	73.6%	69.9%	67.8%
F	14.91	12.60	11.52
N	16	16	16

Source of data: The Bureau of Census in Census of Manufacturers (1973, 1978, 1983) and Annual Survey of Manufacturers (1973, 1978, 1983) and Pollution Abatement cost of Expenditures (1973, 1978,& 1983)

The .5% critical value for t-distribution is 2.5.

The .5% critical value of f-distribution is 2.01.

The T-values are in parentheses.

The results of the empirical estimation of the gross-water output ratio are described in Table VII-A and the intake - gross water ratio are in Table VII-B.

As Table 7 .-A shows, most of the variables had their theoretically expected signs and are significant.

Since the T critical value is 2.1315 and the observed value in part one is 5.679, the null hypothesis must be rejected. It can be concluded that there is a significant relationship between intake water and gross water or significant relationship between assessed value and the heating value . In part two, the critical value of T is also 2.1315 and the observed values are higher than in the first part. It shows significant relationship between intake water and gross water.

Equation (1) shows a very significant price of water as a percent of wage effect on gross water in major water using industries where water is not available in abundance. The coefficient of the price of water as a percent of wage(I) is accompanied on the average by an increase of 33.8 percent in gross water.

The cost of water relative to the total production cost is measured by variable I which has positive effect on the gross water. This shows that the industries in which water is more important relative to the other inputs require more water per unit of output in the production. The use of I in the first equation shows the significance of the price variable of water. This may indicate that the industries which have higher water cost as a percent of total cost are more responsive to changes in the cost of water than those having lower water price ratios. As indicated previously, the (I) may also measure the price effect of non - water inputs(such as materials, output, capital, etc). The coefficient of (the manufacturing price of gross water)pw shows negative sign. This means that gross water increase by 11.9 percent per thousand gallons for every dollar decrease in gross water price when other parameters are held constant or equal to zero. The output(value-added) coefficient indicates a positive sign and shows that an increase of 1.13 percent in output, is accompany on the average by an increase of 1.13 in the demand of gross water.

In the 1978 regression, water as a percent of wage (I) and output (q) have positive signs. That is, if (I) or (q) increase one dollar per thousand gallons when holding the other explanatory variables constant, gross water demand will increase by 25.8 percent and 1.41 percent respectively. This is consistent to the hypothesis. The coefficient of gross water price(q) is negative and it shows that, when gross water price decrease by one dollar per thousand gallons the demand for gross water will increase by -2.01 percent.

In the last equation of part 1, the coefficient of output is 0.46 and the coefficient of water as a percent of wage is 16.9. Both are high as expected. A dollar increase in output or water as a percent of wage, will cause the demand for gross water to decrease by 16.9 percent and 0.46 percent respectfully.

The regression results from industrial water demand estimates indicate that the selected variables performed well in explaining the variation in intake water-gross ratio. The coefficient determination (R) (1973) is 74.2 indicated that 74.2 percent of the variation in intake water-gross water ratio is explained by all the explanatory variables (unit manufacturing cost of recycled water, unit manufacturing cost of intake water, and gross water). In this equation, the unit manufacturing cost of intake water indicated with positive sign. That is, if q price increases by 0.001 dollars per thousand gallons when holding the other explanatory variables constant, the demand for intake-gross water ratio will decrease by 0.001 percent. The coefficient for intake water price is less but, it is significant. Industries that are major water users(such as paper industry) will observe that intake water price plays an important part in the production process.

This is also consistent with the hypothesis. Note that gross water is the sum of q + p_r. The coefficients of manufacturing price of recycled water (p_r) has positive sign. This indicated that for each dollar increase in price per thousand gallons of recycled water, the demand for recycled water will decrease by 0.035 percent holding other explanatory variables constant. Similarly, if gross water price decrease by -0.13 percent dollars per thousand gallons when holding the other explanatory variables constant, the demand for gross water will increase by -0.13 percent. It can be observed that when intake water price increases more than recycled water price, the industry will substitute intake water with recycled water. But when the price of recycled water is higher than intake water, the plant uses intake water.

In the second equation, the coefficient determination (R) is 75.9, which shows that 75.9 percent of the variation in intake-gross water ratio is explained by manufacturing price of intake water (q), manufacturing price of recycled water (p_r), and gross water cost(p_g). The coefficient of p_r has indicated a positive sign in all the three equations. Where b = 0.035 in the first equation , 0.155 in the second equation, and 0.162 in the third equation. Every dollar increase in price per thousand gallons of recycled water, the demand for recycled water will be reduced by 0.035 percent per thousand gallons in the first, 0.155 percent per thousand gallons in the second and 0.162 percent per thousand gallons in the third equation. This means that when manufacturing price of recycled water increases, the demand of intake-gross water ratio decreases by thousand gallons, holding other explanatory variables constant. The coefficient 0.25 is the estimated Value of intake-gross water ratio when both coefficients of IWP and RWP are equal to zero. The coefficient of IWP shows negative sign. It means that one dollar increase in p_r, when other parameters held constant, will result in an increase of demand of intake-gross water ratio.

With the one-tailed student T-Test, at 0.05 level of significant, the result indicates in part I that the values of T-statistic (most of them) are above the T critical value (2.131). Therefore, the null hypothesis must be rejected. It can be concluded that there is a significant relationship between gross water ratio and independent variables.

The results from part I1 show also high coefficients of determination (R) for each equation and some have high t-values for the different combinations of intake-gross water ratios. From table (6), it is observed that as gross water and intake water consumption decreases, the consumption of recycle water increases. But as the cost of recycled water increases, intake water and gross water show little increase in consumption. This can also be observed in the coefficients of determination (R) and the t-values. The t-values show relatively high in part two than in part one.

With the one-tailed student's T-Test, at 0.05 level of significant, the result indicates the positive significant link between demand for intake-gross water ratio and the unit manufacturing cost of intake water and is negatively correlated with demand for gross water and unit manufacturing cost of recycled water. One of the reasons why gross water has negative coefficients is that the decrease in gross water is greater than the decrease in intake water; and also the change in intake-gross ratio is not as fast as the change in gross water annually.

Unit manufacturing cost of water is positive but not significantly different from zero and it also shows low t-values. The low significance of the coefficients show that the production in the 16 manufacturing industries are not significantly affected by the unit manufacturing cost of water.

The estimates of price coefficients variables of water have the expected signs and are overall statistically significant.

The use of cost of water as a percent of income (I) in the first equation has greatly improved the goodness of fit and increased the significance of the price variable of water. This may suggest that the firms which have highest water cost as a percent of total cost are more responsive to changes in the price of water than those lower water cost ratios. The estimated coefficient may also measure the price effect of the non-water inputs. The variable I may also suggest that what is important to the firm is not only the price but the relative price of water and non-water inputs.

The intercepts for intake-gross water ratio are positive in all the equations and are highly significant. This shows that there exist some minimal requirements of gross water and hence intake water for manufacturing water use.

The price coefficients of estimates of water have the expected signs and are generally significant. These are elasticities caused by the logarithm form of the equations. Some chemical industries are more responsive to changes in the price of recycled water than to the price of intake water, but the responses are stored for steel, paper and petroleum. In the production of final output, there are increasing returns to scale for using water. In the recirculation of intake water for paper and steel, scale economies exist, but not for chemical and petroleum. Without changes in the price of water and other factors, more advanced manufacturing technology requires more intake water relative to gross water and more gross water relative to output except for petroleum and steel where less gross water per unit of output is required by new technology. Larger industries have lower productivity of water but higher use rates (for example chemical and steel).

The important of the cost of water relative to total production costs is measured by variable (I); which has positive effects on the water. It means that the industries in which water is more important relative to the other inputs require more water per unit of output in the production. In the first equation variable (I) has improved the goodness of fit and the significance of the price variable of water. The industries which have higher water cost as a percent of total cost may suggest more responsive to changes in the price of water than those having lower water cost ratios. As early noted, the estimated coefficient may also measure the price effect of the non-water inputs(such as labor, capital,etc.).

In second group of equations, the intercepts are positive and highly significant. This means that there exist some minimal requirements of gross water and hence intake water for manufacturing water use. The unit cost of intake water may depend on the amount of intake water withdrawn and the unit cost of recycled water on the amount of water reused and the intercept of recirculation.

Finally, since the intake water per unit of output has fallen for most of the major water-using industries in the United States; manufacturing in the past and may continue to do so, the demand for intake water has not been and will not be simply proportional to the demand for output.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The data presented here are highly aggregated, and apparently considerable technological change in the use of water is occurring over time. The available technologies and the high cost of applying them, marginal shortages in the supply of water can be tolerated even in the major water-using industries.

From the study, the price apparently does affect the purchase of water. As the consumption of water decreasing, the price of water is still increasing.

These notions have several significant planning implications. Industrial water use can, and does, respond to changes in water costs and production technology. The capacity for response is rather significant both over time and during any point in time.

From the study, it is strongly suggested that attention should be given to the changing production process and the location of production facilities which will aid planners in predicting future industrial water needs and allocate the limited resources.

The changes in the production technology appear to be in the water-saving direction, the future demand for industrial water is likely to be even less than would be predicted from today's price response coefficients.

Water use in manufacturing in the United States has been concentrated in a few two-digit SIC industries for each of the five major water-using industries; paper, chemical, petroleum, primary metals, and transportation equipments. The intake water/gross water ratio for most of these industries had been decreasing over the period 1964-1983, and may have continued to fall after 1983. The reduction in the ratios can be attributed to increases both in the productivity of gross water and in the intensity of water recirculation. The recirculation had played a significant role than the productivity of gross water. The relative increase strict water pollution controls has promoted firms to economize on the use of water intake and substitute it with recirculate water.

General observation is that even_though water plays a crucial role in these 16 industries, and price is rapidly increasing, there is little discussion about the impart of water on industrial production.

The study of previous researchers show very little or nothing about the issue of the price elasticity of the demand for industrial water use. These previous researchers show no relationship between water use and water cost. From our observation, our research shows that there is at least in a cross_section analysis of major water use, water use and reuse tempered by relative water costs. The price coefficients in our model show significantly in magnitude and in statistical sense.

Water using industries are basic industries producing commodities which can be recycled. It was found out that steel scrap has encouraged small decentralized mini-mills. There could be some similar recycling possibilities in other industries.

There are three major technological changes taking place that have affected both water use and industry location. The first is specific to water uses and involves various treatment methods, cooling alternatives and the like. This type is stimulated by pollution restriction, and water costs are also relevant. The technology for recirculating cooling most fits this category. Any technology for recirculating cooling most clearly fits this category.

Another change occurs in the actual production technology. These changes most induced by water costs, are perhaps more likely to be responses to other factor costs.

Finally, the paper objective has fallen short. That is, we fall short of our goal. It has been observed that management respond to rising cost of water for industrial use is for greater than really recognized. This has major implications for public policies regarding water demand, water pricing and investment in water resources. It can be observed that rising cost of water has actually decreased the consumption of water in all industries and must be looked into.

For the past years(1956-1983), the price of water has been neglected. This has been due to the notion that cost of water is not significant but non-water factors. Since water cost is increasing, it has now become significant to locate industries near water that consume heavy water.

APPENDIX 1 AND 2

APPENDIX I

The production function is given by:

$$(1)\quad Q = Ae^{mt}\ GW^{a_1}.M_Q^{a_2}.\ L_Q^{a_3}.K_Q^{a_4}$$

The total cost production function is given by:

$$(2)\quad C_H = pGW + g\,M_Q + wL_Q + rK_Q$$

The total cost minimization with respect to all inputs subject to the production function. Partial derivatives with respect to λ and inputs (using the Lagrange function).

(3)

$$Z = pGW+gM_q+wL_q+rK_q+\lambda\,(Q - Ae^{mt}.\ GW^{a_1}.\ M_Q^{a_2}.L_Q^{a_3}.K_Q^{a_4})$$

$$\frac{dZ}{d\lambda} = Q - Ae^{mt}.GW^{a_1}.\ M_Q^{a_2}.\ L_Q^{a_3}.\ K_Q^{a_4}$$

$$\frac{dZ}{dGW} = p - \lambda\,a_1\,(Ae^{mt}.GW^{a_1-1}.\ M_Q^{a_2}.L_Q^{a_3}.K_Q^{a_4}) = 0$$

$$= p - \lambda\,a_1\,\frac{(Ae^{mt}.GW^{a_1}.\ M_Q^{a_2}.\ L_Q^{a_3}.K_Q^{a_4})}{GW} = 0$$

$$p - \lambda a_1 \frac{(Q)}{GW} = 0$$

$$- \lambda a_1 \frac{(Q)}{GW} = P$$

$$\lambda a_1 \frac{Q}{GW} \cdot \frac{1}{\frac{a_1 Q}{GW}} = p \cdot \frac{1}{\frac{a_1 Q}{GW}}$$

[4] $$\lambda = \frac{p}{\frac{a_1 Q}{GW}}$$

$$\frac{dZ}{dM_Q} = g - \lambda\, a_2(Ae^{mt}.GW^{a_1}.M_Q^{a_2-1} . L_Q^{a_3}.K_Q^{a_4}) = 0$$

$$= g - \lambda\, \frac{a_2(Ae^{mt}.GW^{a_1}.\ M_Q^{a_2}.L_Q^{a_3}.K_Q^{a_4})}{M_Q} = 0$$

$$g - \lambda\, a_2 \frac{(Q)}{M_Q} = 0$$

$$\lambda\, \frac{a_2 (Q)}{M_Q} \cdot \frac{1}{\frac{a_2 Q}{M_Q}} = g \cdot \frac{1}{\frac{a_2 Q}{M_Q}}$$

$$[5] \qquad \lambda = \frac{g}{\dfrac{a_2\ Q}{M_Q}}$$

$$\frac{dZ}{dL_Q} = w - \lambda\ a_3\ (Ae^{mt}.GW^{a_1} . M_Q^{a_2} . L_Q^{a_3-1} . K_Q^{a_4}) = 0$$

$$= w - \lambda\ a_3\ \left(\frac{Ae^{mt}.GW^{a_1} . M_Q^{a_2} . L_Q^{a_3} . K_Q^{a_4}}{L_Q}\right) = 0$$

$$w - \lambda\ a_3\ \frac{(Q)}{L_Q} = 0$$

$$\lambda\ a_3\ \frac{(Q)}{L_Q} = w$$

$$\lambda\ a_3\ \frac{(Q)}{L_Q} \cdot \frac{1}{\dfrac{a_3\ Q}{L_Q}} = w \cdot \frac{1}{\dfrac{a_3\ Q}{L_Q}}$$

[6] $$\lambda = \frac{w}{\dfrac{a_3 Q}{L_Q}}$$

$$\frac{dZ}{dK_Q} = r - \lambda a_4 (Ae^{mt}.GW . M_Q^{a_1} . L_Q^{a_2} . K_Q^{a_3} \quad ^{a_4-1}) = 0$$

$$= r - \lambda a_4 \frac{(Ae^{mt}.GW. M_Q^{a_1 a_2} . L_Q^{a_3} . K_Q^{a_4})}{K_Q} = 0$$

$$- \lambda a_4 \frac{(Ae^{mt}.GW. M_Q^{a_1 a_2} . L_Q^{a_3} . K_Q^{a_4})}{K_Q} = r$$

$$- \lambda a_4 \frac{(Q)}{K_Q} = r$$

$$\frac{\lambda a_4 Q}{K_Q} . \frac{1}{\dfrac{a_4 Q}{K_Q}} = r . \frac{1}{\dfrac{a_4 Q}{K_Q}}$$

[7] $$\lambda = \frac{r}{\dfrac{a_4 Q}{K_Q}}$$

The least cost condition can be obtained by establishing that equality between equations (4), (5), (6) and (7).

[8]

$$\lambda = \frac{p}{\frac{a_1 Q}{GW}} = \frac{g}{\frac{a_2 Q}{M_Q}} = \frac{w}{\frac{a_3 Q}{L_Q}} = \frac{r}{\frac{a_4 Q}{K_Q}}$$

Equation (8) is used to solve for GW, M_Q, L_Q, and K_Q.

$$\frac{p}{\frac{a_1 Q}{GW}} = \frac{g}{\frac{a_2 Q}{M_Q}}$$

$$= g \cdot \frac{a_1 Q}{GW} = \frac{a_2 Q}{M_Q} \cdot p$$

$$= \frac{ga_1}{GW} \cdot Q \cdot \frac{1}{Q} = \frac{p.a_2}{M_Q} \cdot Q \cdot \frac{1}{Q}$$

$$ga_1 \cdot M_Q = GW \cdot pa_2$$

[9] $$GW = \frac{ga_1}{pa_2} \cdot M_Q$$

Using the process in equation (8), we obtained:

$$ga_1 \cdot M_Q = GW \cdot pa_2$$

Now we solve for M_Q and obtain

[10]

$$M_Q = \frac{p\ a_2}{ga_1} \cdot GW$$

Solving for L_Q by using equation (8):

$$\frac{\frac{p}{a_1\ Q}}{GW} = \frac{\frac{w}{a_3\ Q}}{L_Q}$$

$$w \cdot \frac{a_1\ Q}{GW} = \frac{a_3\ Q}{L_Q} \cdot p$$

$$\frac{w\ a_1}{GW} \cdot Q \cdot \frac{1}{Q} = \frac{pa_3}{L_Q} \cdot Q \cdot \frac{1}{Q}$$

$$\frac{wa_1}{GW} = \frac{pa_3}{L_Q}$$

[11] $$wa_1 \cdot L_Q = pa_3 \cdot GW$$

$$L_Q = \frac{pa_3 \cdot GW}{wa_1}$$

Solving for K_Q by using equation (8)L:

$$= \frac{\dfrac{p}{a_1 Q}}{GW} = \frac{\dfrac{r}{a_4 Q}}{K_Q}$$

$$r \cdot \frac{a_1 Q}{GW} = p \cdot \frac{a_4 Q}{K_Q}$$

$$\frac{r a_1 Q}{GW} \cdot \frac{1}{Q} = \frac{pa_4 Q}{K_Q} \cdot \frac{1}{Q}$$

[12] $$K_Q \cdot ra_1 = GW \cdot pa_4$$

$$K_Q = \frac{pa_4}{ra_1} \cdot GW$$

From equation (1) (production function), we are going to solve for gross water (GW).

$$Q = Ae^{mt}.GW^{a_1} . MQ^{a_2} . L_Q^{a_3} . K_Q^{a_4}$$

$$\left(\frac{Q}{GWa_1} \right) = \left(Ae^{mt} \frac{GW^{a_1}}{GWa_1} .MQ^{a_2} .L_Q^{a_3} .K_Q^{a_4} \right)$$

$$\left(\frac{Q}{GWa_1} \right)^{-1} = \left\{ Ae^{mt}. \frac{GW^{a_1}}{GWa_1} .MQ^{a_2} .L_Q^{a_3} . K_Q^{a_4} \right\}^{-1}$$

$$\frac{1}{\frac{Q}{GWa_1}} = \frac{1}{Ae^{mt} \; M_Q^{a_2} \; L_Q^{a_3} \; K_Q^{a_4}}$$

$$\frac{Q}{1} \left(\frac{GWa_1}{Q} \right) = \left(\frac{1}{Ae^{mt} \; M_Q^{a_2} \; L_Q^{a_3} \; K_Q^{a_4}} \right) \frac{Q}{}$$

$$GW^{a_1} = \left(\frac{1}{Ae^{mt} \; M_Q^{a_2}} . \frac{1}{L_Q^{a_3}} . \frac{1}{K_Q^{a_4}} \right) \frac{Q}{1}$$

[13]

$$GW^{a_1} = \left(\frac{Q}{Ae^{mt}} \cdot \frac{1}{M_Q^{a_2}} \cdot \frac{1}{L_Q^{a_3}} \cdot \frac{1}{K_Q^{a_4}} \right)$$

Substituting the input demand function (10), (11), (12) into the gross water demand function , equation (13), the result will be gross water equation

$$GW^{a_1} = \frac{Q}{Ae_{mt} \left(\frac{\frac{1}{pa_2}}{ga_1} GW \right)^{a_2} \left(\frac{\frac{1}{pa_3}}{wa_1} GW \right)^{a_3} \left(\frac{\frac{1}{pa_4}}{ra_1} GW \right)^{a_4}}$$

$$GW^{a^1} = \left\{ \frac{Q}{Ae_{mt}} \left(\frac{ga_1}{pa_2} \right)^{a_2} \left(\frac{wa_1}{pa_3} \right)^{a_3} \left(\frac{ra_1}{pa_4} \right)^{a_4} \right\}^{\frac{1}{a_2+a_3+a_4}} GW$$

Dividing both sides of this equation above by

$\frac{GW^{a_2+a_3+a_4}}{1}$, you will obtain:

$$GW^{a_1+a_2+a_3+a_4} = \frac{Q}{Ae_{mt}} \left(\frac{ga_1}{pa_2} \right)^{a_2} \left(\frac{wa_1}{pa_3} \right)^{a_3} \left(\frac{ra_1}{pa_4} \right)^{a_4}$$

If you divide both sides of the below equation by this power ($\frac{1}{a_1+a_2+a_{+3}a+_4}$), you will obtain gross water equation.

$$GW^{a_1+a_2+a_3+a_4} = \left\{ \frac{Q}{Ae_{mt}} \left(\frac{ga_1\ a_2}{pa_2}\right) \left(\frac{wa_1\ \ a_3}{pa_3}\right) \left(\frac{ra_1 a_4}{pa_4}\right)^{a_4} \right\}$$

This is gross water equation:

(14)

$$GW = \left\{ \frac{Q}{Ae_{mt}} \left(\frac{ga_1}{pa_2}\right)^{a_2} \left(\frac{wa_1}{pa_3}\right)^{a_3} \left(\frac{ra_1}{pa_4}\right)^{a_4} \right\}^{\frac{1}{a_1+a_2+a_3+a_4}}$$

Dividing both sides of the equation (14) by Q, we obtain:

$$\frac{GW}{Q} = \left\{ \frac{Q^s}{Ae_{mt}} \left(\frac{ga_1}{pa_2}\right)^{a_2} \left(\frac{wa_1}{pa_3}\right)^{a_3} \left(\frac{ra_1}{pa_4}\right)^{a_4} \right\}^{\frac{1}{a_1+a_2+a_3+a_4}}$$

Where $s = 1 - a_1 - a_2 - a_3 - a_4$

This is the gross water output ratio and is expressed theoretically as a function of the level of output, technology, and relative g/p, w/p, r/p. More specifically, gross water use per unit output is inversely related to growth of water saving technology, an inverse function of its own price,p, and directly related to the price of materials, g, wages, w, and the rate of returns to scale. The impact of increase output on

gross-water/output ratio is indeterminate but depends upon the returns to scale.

If $a_1+a_2+a_3+a_4 = 1$, then changes in output does not impact on gross water output ratio. If $\Sigma ai > 1$ or $\Sigma ai < 1$ then $1 - \Sigma ai < 1$ increasing output lower the demand for water, and if $\Sigma ai < 1$, then $1 - \Sigma ai > 0$ and increase output raises the demand for gross water. Thus the response to gross water demand caused by output changes depends upon technical condition that surrounds production.

APPENDIX II

The production function of gross water is assumed to be:

[15]

$$GW = Be^{at} \; IW^{d_1} . M_R^{d_2} . L_R^{d_3} . K_R^{d_4}$$

where the total cost of water is assumed to be:

[16] $$C_w = q.IW + h.M_R + w.L_R + r.K_R$$

Minimizing equation (16) subject to equation (15), the Lagrange function is used and partial derivatives are taken with respect to intake water (IW), materials (M), labor (L) and capital (K).

$$X = qIW+hM_R+wL_R+rK_R+ \; (GW-Be^{at}.IW^{d_1}.M_R^{d_2}.L_R^{d_3}.K_R^{d_4})$$

$$\frac{dX}{d\lambda} = GW - Be^{at}.IW^{d_1}.M_R^{d_2}.L_R^{d_3}.K_R^{d_4}$$

$$\frac{dX}{dIW} = q - \lambda \, d_1 \, (Be^{at}.IW^{d_1-1}.M_R^{d_2}.L_R^{d_3}.K_R^{d_4}) = 0$$

$$= q - \lambda \, d_1 \left(\frac{Be^{at}.GW}{\overset{d_1}{IW}}{}^{d_1}.M_R^{d_2}.L_R^{d_3}.K_R^{d_4}\right) = 0$$

$$q - \lambda d_1 \left(\frac{GW}{IW}\right) = 0$$

$$\left(\frac{1}{\frac{GW}{IW}}\right) - \lambda d_1 \left(\frac{GW}{IW}\right) = - q \cdot \frac{1}{\frac{GW}{IW}}$$

[17] $$\lambda = \frac{q}{\frac{GW}{IW}}$$

$$\frac{dX}{d} = h - \lambda d_2 \left(B.e^{nt}.IW^{d_1}.M_R^{d_2-1}.L_R^{d_3}.K_R^{d_4}\right) = 0$$

$$= h - \lambda d_2 \left(B.e^{nt}.IW^{d_1} . \frac{M_R^{d_2-1}.L_R^{d_3}.K_R^{d_4}}{M_R}\right) = 0$$

$$h - \lambda da_2 \left(\frac{GW}{M_R}\right) = 0$$

$$- \lambda da_2 \left(\frac{GW}{M_R}\right) = -h$$

$$\frac{1}{\frac{da_2GW}{M_R}} - \lambda da_2 \left(\frac{GW}{M_R}\right) = -h \cdot \frac{1}{\frac{GWd_2}{M_R}}$$

[18]

$$\lambda = \frac{\frac{h}{da_2 GW}}{M_R}$$

$$\frac{dX}{d} = w - \lambda\, d_3\, (B.e^{nt}.IW^{d_1}.M_R^{d_2}.L_R^{d_3-1}.K_R^{d_4}) = 0$$

$$w - \lambda\, d_3 \frac{GW}{L_R} = 0$$

$$- \lambda\, d_3 \frac{GW}{L_R} = - w$$

$$- \frac{1}{d_3 \frac{Gw}{L_R}} . - \lambda\, d_3 \frac{GW}{L_R} = w . \frac{\frac{1}{d_3\ GW}}{L_R}$$

[19]

$$\lambda = \frac{\frac{w}{d_3\ GW}}{L_R}$$

$$\frac{dX}{d} = r - \lambda\, d_4\, (B.e^{nt}.IW^{d_1}.M_R^{d_2}.L_R^{d_3}.K_R^{d_4-1}) = 0$$

$$= r - \lambda \, d_4 \left(B.e^{at}.IW^{d_1}.M_R^{d_2}.L_R^{d_3}.\frac{K_R^{d_4}}{K_R} \right) = 0$$

$$r - \lambda \, d_4 \frac{GW}{K_R} = 0$$

$$- \lambda \, \frac{d_4 \, GW}{K_R} = - r$$

$$\frac{1}{\frac{d_4 \, GW}{K_R}} . \lambda \, \frac{d_4 \, GW}{K_R} = - r . \frac{1}{\frac{d_4 GW}{K_R}}$$

[20]

$$\lambda = \frac{r}{\frac{d_4 \, GW}{K_R}}$$

[21]

$$\lambda = \frac{q}{\frac{d_1 GW}{IW}} = \frac{h}{\frac{d_2 \, GW}{M_R}} = \frac{w}{\frac{d_3 GW}{L_R}} = \frac{r}{\frac{d_4 GW}{K_R}}$$

Where is the marginal cost of gross water. Equation [21] will be used to solve for M_R. L_R, and K_R .

Solving for M_R :

$$\frac{\frac{q}{d_1 GW}}{IW} = \frac{\frac{h}{d_2\ GW}}{M_R}$$

$$h \cdot \frac{d_1 GW}{IW} = \frac{d_2\ GW}{M_R} \cdot q$$

$$\{ \frac{hd_1}{IW} \} GW = [\{ \frac{d_2\ q}{M_R} \} GW] \frac{1}{GW}$$

$$\frac{hd_1}{IW} = \frac{d_2\ q}{M_R}$$

$$hd_1 \cdot M_R = IW \cdot d_2\ q$$

[22]

$$M_R = \frac{d_2\ q}{hd_1} IW$$

Solving for L_R :

$$\frac{\frac{q}{d_1 GW}}{IW} = \frac{\frac{w}{d_3 GW}}{L_R}$$

$$w \cdot \frac{d_1 GW}{IW} = \frac{d_3 GW}{L_R} \cdot q$$

$$\left\{ \frac{wd_1 GW}{IW} = \frac{qd_3 GW}{L_R} \right\} \frac{1}{GW}$$

$$\frac{d_1\ w}{IW} = \frac{q\ d_3}{L_R}$$

$$L_R \cdot w.d_1 = IW \cdot q.d_3$$

[23]

$$L_R = \frac{q.d_3}{w.d_1} IW$$

Solving for K_R :

$$\frac{\dfrac{q}{d_1 GW}}{IW} = \frac{\dfrac{r}{d_4 GW}}{K_R}$$

$$r \cdot \frac{d_1 GW}{IW} = \frac{d_4 GW}{K_R} \cdot q$$

$$GW\left(\frac{d_1\ r}{IW}\right) = \left\{\left(\frac{d_4\ q}{K_R}\right)GW\right\}\frac{1}{GW}$$

$$\frac{d_1\ r}{IW} = \frac{d_4\ q}{K_R}$$

$$d_1\ rK_R = IWd_4\ q$$

[24]

$$K_R = \frac{d_4\ q}{d_1\ r}\ IW$$

From equation (15) (production function for gross water), we are going to solve for intake water (IW).

$$\frac{GW}{IW^{d_1}} = Be^{\alpha t}\frac{IW}{IW^{d_1}} \cdot M_R^{d_2} \cdot L_R^{d_3} \cdot K^{d_4}$$

We raise both sides of the equations by -1

$$\left\{ \frac{GW}{IW^{d_1}} \right\}^{-1} = \left\{ (Be^{\alpha t})(M_R^{d_2})(L_R^{d_3})(K_R^{d_4}) \right\}^{-1}$$

$$\frac{1}{\frac{GW}{IW^{d_1}}} = \frac{1}{Be^{\alpha t}\,(M_R^{d_2})\,(L_R^{d_3}\,.)\,(K_R^{d_4})}$$

$$\frac{1}{GW}\left(\frac{IW^{d_1}}{GW}\right) = \left\{ \frac{1}{Be^{\alpha t}} . M_R^{\frac{1}{d_2}} . L_R^{\frac{1}{d_3}} . K_R^{\frac{1}{d_4}} \right\} \frac{GW}{1}$$

[25]

$$\overline{IW^{d_1}} = \frac{GW}{Be^{\alpha t}} \left(M_R^{\frac{1}{d_2}}\right)\left(L_R^{\frac{1}{d_3}}\right)\left(K_R^{\frac{1}{d_4}}\right)$$

Substituting the input demand functions, equation (22), (23),and (24) into the gross water demand function, equation (25), the result will be intake water(solving for intake water).

$$IW^{d_1} = \left(\frac{GW}{B\ e^{nt}} \right) \frac{1}{\left(\frac{d_2\ q}{hd_1} IW \right)^{d_2}} \cdot \frac{1}{\left(\frac{d_3\ h}{wd_1} IW \right)^{d_3}} \cdot \frac{1}{\left(\frac{d_4\ r}{rd_1} IW \right)^{d_4}}$$

$$IW^{d_1} = \left\{ \left(\frac{GW}{B\ e^{nt}} \right) \left(\frac{hd_1}{qd_2} \right)^{d_2} \left(\frac{wd_1}{qd_3} \right)^{d_3} \left(\frac{rd_1}{qd_4} \right)^{d_4} \right\} \frac{1}{IW^{d_2+d_3+d_4}}$$

Multiplying both sides of the equation above by the

power $\left(\frac{GW}{1} \right)^{d_2+d_3+d_4}$, we obtain:

$$[IW^{d_1+d_2+d_3+d_4} = \left\{ \frac{GW}{Be_{nt}} \left(\frac{hd_1}{qd_2} \right)^{d_2} \left(\frac{wd_1}{qd_3} \right)^{d_3} \left(\frac{rd_4}{qd_4} \right)^{d_4} \right\}$$

Multiplying both sides of the equation above by the power

$\left(\frac{1}{d_1+d_2+d_3+d_4} \right)$, we will obtain gross water equation.

$$(IW = \left\{ \frac{GW}{Be_{nt}} \left(\frac{hd_1}{qd_2} \right)^{d_2} \left(\frac{wd_1}{qd_3} \right)^{d_3} \left(\frac{rd_4}{qd_4} \right)^{d_4} \right\}^{\frac{1}{d_1+d_2+d_3+d_4}}$$

Dividing both sides of equation above by GW, we will obtain:

$$\frac{IW}{GW} = \left\{ \frac{GW^{s}}{Be_{at}} \frac{(hd_1)}{qd_2} d_2 \frac{(wd_1\ )}{qd_3} d_3 \frac{(rd_4\ )}{qd_4} d_4 \right\}^{\frac{1}{d_1+d_2+d_3+d_4}}$$

Where $s = 1-d_1-d_2-d_3-d_4$

Thus the intake water/gross water-ratio that has been expressed theoretically as a function of the level of output, technology, and relative price h/q, w/q, r/q to be more exact water use per unit of output is inversely related to growth of water saving technology, an inverse function of its own price, q, and directly related to the price of materials, h, wages, w, and the rate returns to capital. The impact of increased output on intake water/gross-water ratio is indeterminate but depends upon the returns to scale.

If $d_1+d_2+d_3+d_4 = 1$, then changes in output does not impact the intake water/gross water ratio. If $\Sigma ai > 1$ or $\Sigma ai < 1$ then $1 - \Sigma ai < 1$ increasing output lowers the demand for intake water, and if $\Sigma ai < 1$ then $1 - \Sigma ai > 0$ and increasing output rises the demand for intake water/gross water-ratio. Thus the response to intake water/gross water ratio changes depends upon the technical condition that surrounds production

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